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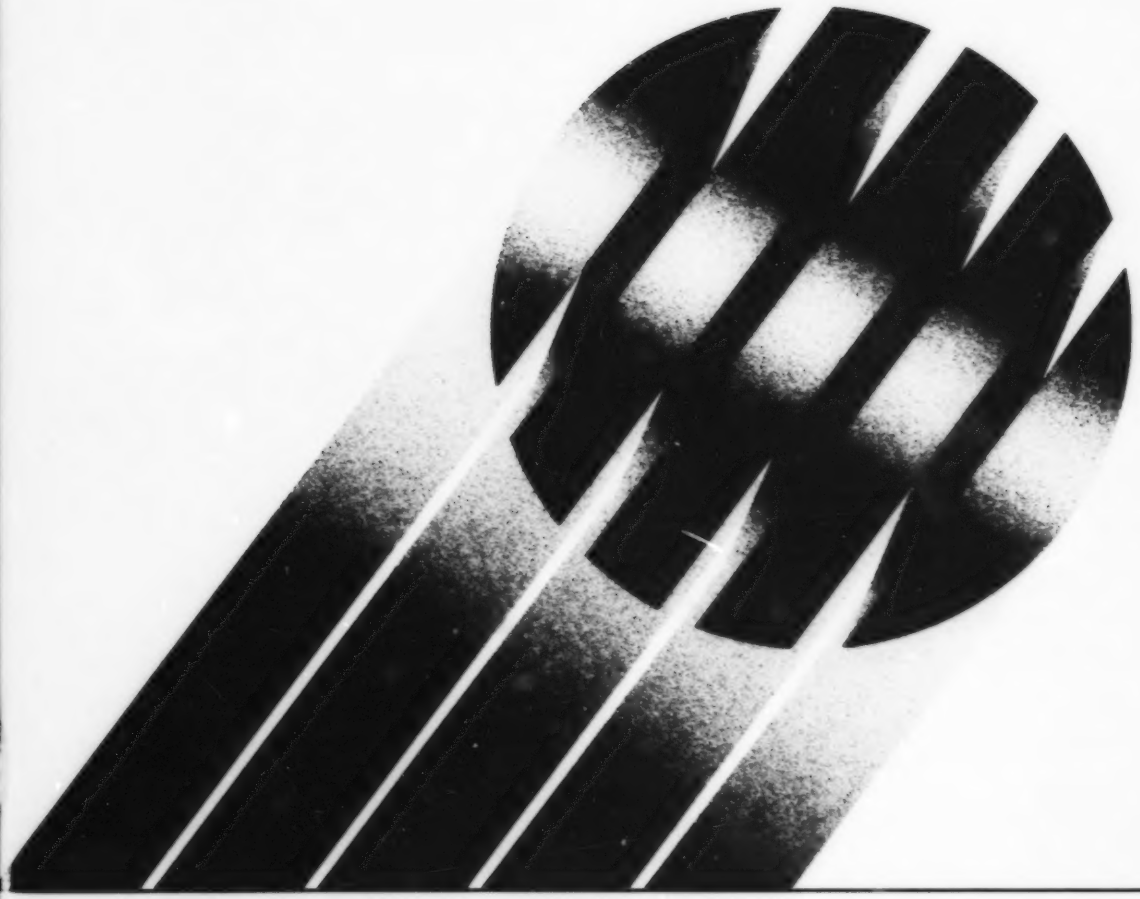
Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

SUMMARY REPORT NO. 12: PHOSPHATE

R.K. COLLINGS
Mineral Processing Laboratory

MINERAL SCIENCES LABORATORIES



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R.K. Collings
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March 1991

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SUMMARY REPORT NO. 12: PHOSPHATE

by

R.K. Collings*

Abstract

Phosphate commonly occurs in igneous rocks as the mineral apatite or fluorapatite and in sedimentary rocks as francolite, a carbonate fluorapatite. Canadian phosphate deposits may be grouped into three main categories and locations: metamorphoric, chiefly located in southeastern Ontario and southern Quebec; carbonatite (phosphate-enriched carbonates), chiefly located in Ontario and Quebec; and sedimentary, chiefly located in southeastern British Columbia and southwestern Alberta.

Phosphate is chiefly used in the manufacture of phosphate fertilizers and elemental phorphorus, the latter in turn being used in the manufacture of phosphate chemicals. Canada's requirement of phosphate rock for fertilizer and chemicals manufacture currently is imported, there being no domestic production. Imports are in the order of 2 Mt annually and mostly are from the United States and Togo.

Phosphate fertilizers are produced at four plants in Canada, one in New Brunswick, two in Alberta, and one in British Columbia. Elemental phosphorus and phosphate chemicals are produced at two plants in Quebec and at one in Ontario.

Potential by-products of the manufacture of phosphate fertilizer and phorphorus operations include uranium, vanadium, fluorine, phosphogypsum, and calcium phosphate slag. Fluorine is recovered as fluosilicic acid for water fluoridation and calcium silicate slag, on occasion, may be used as aggregate in road and embankment construction.

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*Former Head, Industrial Mineral Section, Mineral Processing Laboratory, CANMET, Energy, Mines and Resources Canada, Ottawa, Ontario, K1A 0G1.

Interest in phosphate in Canada is largely confined to two deposits in northeastern Ontario; however, their development must await improvement in prices and a more favourable balance between supply and demand.

CANMET's investigation of phosphate deposits has been limited owing to a general non-interest in the development of domestic phosphate resources by industry. Of the thirteen investigations summarized in Appendix A, all except one were conducted in the 1940s and 1950s. A study by the Quebec Department of Mines, summarized in Appendix B, also was made in the 1940s.

RAPPORT SOMMAIRE N° 12 : LE PHOSPHATE

par

R.K. Collings*

Résumé

Le phosphate se présente généralement dans des roches ignées sous la forme des minéraux apatite ou fluorapatite, et dans des roches sédimentaires sous la forme de francolite, une fluorapatite carbonatée. Au Canada, les gisements de phosphate se classent en trois grandes catégories qui se rencontrent dans trois régions principales : les gisements métamorphiques qu'on trouve principalement dans le sud-est de l'Ontario et le sud du Québec; les gisements de carbonatite (carbonates riches en phosphate), surtout en Ontario et au Québec, et les gisements sédimentaires, qui se trouvent en grande partie dans le sud-est de la Colombie-Britannique et le sud-ouest de l'Alberta.

Le phosphate sert principalement à la fabrication d'engrais phosphatés et de phosphore élémentaire, ce dernier étant utilisé pour fabriquer des produits chimiques phosphatés. Actuellement, au Canada, il n'y a aucune production de roches phosphatées pour la fabrication d'engrais et de produits chimiques, et les importations répondent à la demande interne. En effet, les importations de roches phosphatées, qui proviennent surtout des États-Unis et du Togo, sont de l'ordre de 2 000 000 t/a.

La production d'engrais phosphatés se fait à quatre usines au Canada, dont une au Nouveau-Brunswick, deux en Alberta et une en Colombie-Britannique. Le phosphore élémentaire et les produits chimiques phosphatés sont fabriqués dans deux usines, l'une au Québec et l'autre en Ontario.

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*Ancien chef, Section des minéraux industriels, Laboratoire de traitement des minéraux, CANMET, Énergie, Mines et Ressources Canada, Ottawa (Ontario) K1A 0G1.

Les sous-produits éventuels de la fabrication d'engrais phosphatés et de phosphore comprennent l'uranium, le vanadium, la fluorine, le phosphogypse et le laitier de phosphate de calcium. La fluorine est récupérée sous la forme d'acide fluosilicique et sert à la fluorisation de l'eau; le laitier de silicate de calcium sert parfois de granulat employé à des fins de construction routière et de remblaiement.

Il existe deux grands gisements de phosphate au Canada, dans le nord-est de l'Ontario; toutefois, ils ne pourront être mis en valeur tant qu'il n'y aura pas hausse des prix et amélioration de l'équilibre entre l'offre et la demande.

CANMET a peu étudié les gisements de phosphate puisqu'en général, l'industrie ne s'intéresse pas à la mise en valeur des ces ressources intérieures. L'annexe A présente un résumé de treize études; toutes ces études sauf une ont été menées dans les années 1940 et 1950. L'annexe B présente un résumé d'une étude effectuée dans les années 1940 par le Ministère des mines du Québec.

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INTRODUCTION

The response to a CANMET survey of industrial mineral producers (1), and subsequent discussions with industry and government specialists, identified a requirement for information on industrial minerals in a number of areas including: mineral deposits, processing and beneficiation techniques and studies, product specifications and markets, and current developments.

In response to this requirement and in light of the fact that CANMET and its predecessor, Mines Branch, have been directly involved in R&D studies on mineral samples from many of the industrial mineral deposits of Canada, a decision was made to compile related information on file in CANMET and EMR generally, in provincial government offices and, as available, from the private sector, in a series of Summary Reports on a number of industrial minerals. Reports for each mineral would contain information pertaining to mineral occurrences, deposits of specific interest, current activities, product uses and specifications, process technology, and summaries of past R&D on specific deposits by CANMET and others, as available. This report, *Summary Report No. 12: Phosphate*, is the twelfth in this series.

GEOLOGY AND MINERALOGY (2,3)

Phosphate occurs in all igneous and sedimentary rocks. From the standpoint of potential commercial exploitation, the most important mineral in igneous rocks is fluorapatite, $Ca_5(PO_4)_3F$, which contains about 42% P_2O_5 and 3.8% F_2 and, in sedimentary rocks, francolite, a carbonate fluorapatite containing up to 2% molecular CO_2.

Igneous deposits of commercial interest commonly occur in intrusive complexes of alkalic rocks which are characterized by ring-like, concentric structures that may be 1.5 to 10 km in diameter. These structures commonly encompass veins and larger bodies of enriched

carbonates (calcite, dolomite, siderite, and ankerite) at or near their centres. Such carbonate concentrations are called carbonatites and commonly contain the mineral apatite which also may occur in the alkalic rocks that are located outward from the central carbonatite.

The mica-apatite-calcite deposits in southwestern Quebec and southeastern Ontario occur in irregular, pockety masses in pyroxenite. The pyroxenites represent metamorphosed limestones which have been engulfed by immense batholithic masses of granite. The calcite probably represents calcium carbonate that was dissolved from the limestone by heated waters and redeposited in cavities in the pyroxenite, whereas the mica is of contact-metamorphic origin. Some of these deposits may contain apatite as the principal mineral although most are composed of calcite, mica and apatite in varying amounts.

Sedimentary phosphate deposits are of two types: guano and pelletal. Guano deposits result from the accumulation of animal excrement, principally that of large sea birds, whereas pelletal deposits are of marine formation and are commonly associated with dolomite or limestone. The francolite of pelletal, sedimentary phosphate deposits was originally emplaced as small pellets and has persisted in that form, the size of such pellets ranging from 0.25 to 0.35 mm. Practically all deposits of pelletal phosphate represent original calcium carbonate of diverse origin that has subsequently become phosphatized by phosphate ions in sea water. Pelletal phosphate beds are frequently of large areal extent and may be 3 to 4 m or more in thickness. The phosphate content of rock beds may range from 1 or 2% P_2O_5 up to practically pure francolite pellets which contain about 35% P_2O_5. Associated minerals commonly include quartz, chert, dolomite and calcite. Pelletal phosphate deposits additionally typically contain from 0.001 to 0.02% U_3O_8.

DEPOSITS

Barry (4) divides known Canadian phosphate deposits into three main categories: apatite deposits contained in metamorphic rocks, and principally located in southeastern Ontario and southwestern Quebec; apatite deposits associated with carbonate-alkaline (carbonatite)

complexes in Ontario and Quebec; and sedimentary phosphate deposits in the southern Rocky Mountains in British Columbia and Alberta and, to a lesser degree, in Quebec. Carbonatite deposits have recently been identified in British Columbia (5). A number of the principal known occurrences are noted on the map in Fig. 1.

Metamorphic

As previously noted, known metamorphic-type apatite deposits are mostly located in southeastern Ontario and southwestern Quebec. In Ontario, the apatite is principally contained in narrow veins or disseminated in crystal form in calcite. Occurrences in Ontario are chiefly confined to an area ranging from 25 to 75 km due north of Kingston, in North Burgess township, Lanark county, and in Bedford and Loughborough townships, Frontenac county. In Quebec, the apatite most commonly occurs as large, irregularly shaped deposits in pyroxenite host rock. The Quebec occurrences largely are confined to the area lying between and adjacent to the Lièvre and Gatineau rivers, immediately north of the Ottawa river and extending to about 40 km north of that river. Spence (3) records a multitude of occurrences in this area, principally in Hull, Wakefield, Templeton, Buckingham, and Portland East and West townships, Labelle county.

Many of the apatite deposits in Ontario and Quebec were mined during the period 1870 to 1919. Over 300,000 t were produced and mostly used for the manufacture of fertilizers in Ontario and Quebec and, as well, in Great Britain. The production of phosphate in Canada essentially ceased in the early 1900s because of competition from lower cost sedimentary deposits that were brought into production in Florida.

Carbonatite

A number of carbonatite-type deposits of apatite are known in Ontario and Quebec, in British Columbia, and in the Northwest Territories; however, deposits having potential commercial

Fig. 1 - Principal Phosphate Occurrences in Canada

interest are few, the two more important being in Ontario near Cargill, 32 km southwest of Kapuskasing, and near Nemegos, about 160 km north and east of Sault St. Marie.

Cargill

The Cargill phosphate occurrence has been well described by Sandrik and Erodosh (6). This alkaline deposit is composed principally of carbonatite and pyroxenite-amphibolite rocks. The section of particular interest consists of a thick residual enriched leached carbonatite zone capped by troughs and sinks filled with apatite residuum, the whole being overlain by 5 to 165 m of clay overburden. The carbonatite is reported to contain 5 to 15%, the leached carbonate 20 to 40%, and the residuum 20 to 98% apatite. The residuum ranges from zero thickness on ridges to more than 170 m in troughs and sinks. This residue, the ultimate product of chemical weathering of the carbonatite, comprises 80 to 90% of the total orebody. It occurs as an unconsolidated material of predominantly sand-size range and principally consists of colourless apatite crystals and crystal fragments. It is reported that vermiculite, clay minerals, quartz sand and columbium-bearing minerals are present in significant amounts and may be of interest for possible commercial developments. This deposit has been evaluated by several companies in the last 15 years.

Nemegos

The Nemegos phosphate deposits are described as being replacement deposits in an alkaline-carbonatite complex. Minerals present include apatite, titaniferous magnetite, pyrochlore and calcite. These deposits have been studied as a commercial source of phosphate on a number of occasions in the past 35 years or more and several large ore zones, grading 21.3% apatite, 13.7% magnetite, and 0.19% columbium oxide, have been identified (7).

Other

Significant phosphate mineralization has been identified in a number of other carbonatite deposits in Ontario, Quebec, and British Columbia. Sage (7) notes a number of such occurrences including those in Valentine Township, District of Cochrane; Prairie Lake, Thunder Bay District; and Schryburt Lake and Big Beaver House, District of Kenora. Jacob et al. (8) list no fewer than twenty-five deposits in Quebec. These deposits are associated with alkaline complexes in the southeastern part of the province, west of the St. Lawrence River. Of particular interest because of associated niobium are four deposits in the Oka carbonatite complex. Apatite occurs as pockets and lenses and represents from 10 to 30% of the deposit. Phosphate content ranges from 7 to 12% P_2O_5 and reserves have been estimated at 25 Mt. Other deposits of interest include those at Saint-Honoré, north of Chicoutimi; at Mont Saint-Hilaire, east of Montreal; and near Harve-Saint-Pierre, on the north shore of the St. Lawrence River, north of Anticosti Island. The Saint-Honoré deposit, at one time operated by Niobec Mines Ltd. for niobium, reportedly contains reserves of over 12 Mt grading 6 to 8% apatite. Tests showed that rejects from a niobium pilot plant could be upgraded to 33.9% P_2O_5 with a recovery of 78.5%. Mont Saint-Hilaire apatite was investigated by Chess Mining Corporation in the 1950s. Grades of 34.4 to 39.3% P_2O_5 were obtained with recoveries of 42 to 45%. The Harve-Saint-Pierre apatite occurs in massive anorthosite and is associated with iron and titanium oxides. Apatite forms 8 to 10% of the rock mass at Lac Puyjalon northeast of Harve-Saint-Pierre. Tests to recover associated ilmenite resulted in a by-product apatite analyzing 30.7% P_2O_5 with a recovery of 64.6%. Reserves of 230 Mt containing 10.8% TiO_2, 17.9% Fe, and 3.0% P_2O_5 have been reported.

Butrenchuk (5) describes two apatite-bearing carbonatite deposits in eastern British Columbia, the Aley carbonate north of MacKenzie and the Verity carbonate north of Blue River. The Aley carbonate complex is oval-shaped, 3 to 3.5 km in diameter, and consists of a dolomite-calcite-carbonatite core with an outer ring of metasomatically altered syenite. The average grade of the carbonatite has been estimated at 5% P_2O_5. The Verity carbonate is a tubular

ody that has undergone intense structural deformation. Grades of from 2 to 5% P_2O_5 have been reported.

Sedimentary

Sedimentary phosphate deposits have been identified in British Columbia, Alberta, Saskatchewan, Yukon Territory, and in the District of MacKenzie in the west and, in the east, in Quebec.

Sedimentary phosphate beds of Jurassic and older age occur in British Columbia and Alberta in the southern Rocky Mountains between Jasper and the International Boundary. These beds lie at the base of the Fernie formation which is well exposed in an area extending from Fernie east to the British Columbia-Alberta border, and from the International Boundary northward to the headwaters of the Elk River. The British Columbia deposits have been studied in recent years by Butrenchuck (9) who describes 29 deposits in the general Fernie area. The phosphate beds are relatively thin, from 1 to 3 m in thickness, and overlain by up to 30 m of shale. Phosphate grades of from 10 to 25% P_2O_5 have been reported. MacDonald (10) reports on extensions of the Fernie phosphate eastward into Alberta. The best resource potential in Alberta are those deposits in the Crowsnest Pass area, immediately adjacent to the Alberta-British Columbia border. Grades of from 1 to 15% P_2O_5 have been recorded.

Sedimentary phosphate occurrences have been identified in the Athahasca Basin in Saskatchewan, and in the north Richardson Mountains, Yukon Territory and District of MacKenzie (11).

Apatite occurs as grains and as matrix in fine-grained sandstone, siltstone, and intraformational conglomerate of the Wolverine Point Formation in the upper part of the Athabasca Group. Grades up to 20% P_2O_5 are reported. Sub-economic but substantial phosphate values are associated with iron- and manganese-bearing clastic sediments of

Cretaceous age in the northern Richardson Mountains, Yukon Territory and District of Mackenzie. The iron-phosphate deposits lie in the vicinity of Rapid Creek, Big Fish River, and Cache Creek, west of the Mackenzie Delta. Phosphate grades as high as 30% P_2O_5 have been noted (12).

Jacob et al. (8) have recorded four sedimentary phosphate occurrences in Quebec as follows: Rivière Quelle on the south shore of the St. Lawrence River, opposite Baie St. Paul; Rapide-des-Alumettes on the Ottawa River, east of Petawawa; near Grenville on the Ottawa River north of Hawkesbury; and at Phillipsburg, southeast of Montreal near the International Boundary. Jacob does not consider these deposits to be of economic importance.

A number of the above-noted deposits are briefly described in Table 1.

USES AND SPECIFICATIONS (1,2)

About 80% of the phosphate rock consumed in Canada is used in the manufacture of phosphate fertilizers and chemicals. The remaining 20% is used in the manufacture of elemental phosphorus (4).

Phosphate Fertilizers

Phosphate fertilizers are added to soils to supply essential nutrients for plant growth. A number of phosphate and phosphate-based fertilizers are used, the more important of which are listed in Table 2.

The starting raw material for phosphate fertilizer production is phosphate rock. Phosphate rock is acidulated with concentrated sulphuric acid to produce phosphoric acid and a by-product calcium sulphate. The phosphoric acid is further reacted with phosphate rock to produce higher grades of phosphate fertilizer, notably triple superphosphate.

Table 1 - Canadian Phosphate Possibilities (11)

Phosphate Province	Location	Remarks	Factors in Production
Ontario	Cargill	Residual capping on carbonatite, estimated 56.7 Mt of 19.6% P_2O_5.	Co-products (silica, kaolinite) possibly available. Close to railways, but distant from markets.
	Nemegos	Apatite-magnetite body in carbonatite, estimated 34.5 Mt of 9.2% P_2O_5.	Co-products available (Fe, Nb). Reasonably close to railway.
	Schryburt Lake	Residual capping, grades 18.5 - 19.5% P_2O_5, size unknown.	Tonnage uncertain, remote from transport.
	Martison Lake	Residual capping on carbonatite.	
Western Canadian Shield	Athabasca Basin, Saskatchewan	Wolverine Point Formation; grains and matrix apatite in siltstone-mudstone, sandstone and intraformational breccia-conglomerate.	Remote; mining conditions probably fair; no power source developed; grades and thicknesses not known.
Southern Canadian Rockies	Alberta Trough: Fernie Synclinorium, British Columbia	Basal 1-3 m of Fernie Group pelletal phosphorite with shale; grades about 25% P_2O_5, decreasing upward. Main target for phosphate exploration since 1920s. Tonnages have been estimated at several localities where beds parallel slope, so that strip mining feasible.	Access good; mining conditions poor; power sources available; proven tonnages; uranium co-product available.
Northern Cordillera	Northern Richardson Mts., Dist. of Mackenzie, Yukon Territory	Siderite-pyrite-apatite siltstones associated with flyschoid rocks; manganese values also. Rough calculations of reserves have been made using average composition: Fe_2O_3 33%, P_2O_5 14%, MnO 5%, 27 Gt.	Extremely remote; mining conditions not known, probably fair; climatic conditions: arctic; no power source developed; grades and tonnages estimated; co-products (Fe, Mn).

Table 2 - Selected Phosphorus Sub-Products (11)

	Nitrogen N %	Phosphorus (P_2O_5) %	Potassium (K_2O) %
Phosphate Rock		28 to 37	
Phosphoric Acid		28 to 54	
Superphosphoric Acid		70 to 100	
Phosphatic Fertilizers			
Diammonium phosphate (DAP)	18	46	0
Monoammonium phosphate (MAP)	11	48	0
Triple superphosphate (TSP)	0	46	0
Ammonium nitrate phosphate	23	23	0
Ammonium phosphate sulphate	16	20	0
Superphosphate (SSP)	0	20	0
Blended fertilizer	15	15	15
Calcium phosphate		18.5 to 21% P	

Various elements typically present in phosphate rock may be troublesome in the acidulation process. These include iron, aluminum, calcium, magnesium, iron sulphides, chlorides, fluorides, and carbon. Iron and alumina form insoluble phosphate and decrease filtration rates, iron and aluminum oxides combined should be less than 4% and preferably less than 2.5%; the weight ratio of calcium to phosphate ($CaO:P_2O_5$) should not exceed 1.6:1 as surplus calcium results in excessive consumption of sulphuric acid; magnesium as magnesia (MgO) should not exceed 0.25% as magnesium also consumes sulphuric acid and, as well, decreases the viscosity of the phosphoric acid and liquid fertilizers; chlorides should not exceed 0.13% as chlorides contribute significantly to the early corrosion of processing equipment; iron sulphides and fluorides should be low to limit the possible formation of noxious hydrogen sulphide and hydrogen fluoride gases; and organic matter (carbon), in excess, causes foaming during the acidulation process and decreases filtration rates.

Superphosphoric acid is made by concentrating wet process phosphoric acid by evaporation and is used in combination with ammonia in the production of granulated and liquid fertilizers. Other common fertilizers include ammonium nitrate phosphate, a mixture of ammonium nitrate and ammonium phosphate, and ammonium phosphate sulphate, a mixture of ammonium phosphate and ammonium sulphate.

Elemental Phosphorus

Elemental phosphorus is formed in an electric furnace by the reduction of phosphate rock with coke and silica. The generated phosphorus gas is condensed by water spray and pumped to storage tanks. Most elemental phosphorus is use to produce high-purity phosphoric acid which, in turn, is used as a base chemical for the production of sodium phosphate compounds for the detergent industry, and calcium phosphate compounds for the food industry.

Red or amorphous phosphorus derived from elemental phosphorus is used by the match industry, in incendiaries, in other pyrotechnical applications, in the metals industry for the production of various phosphate compounds, and in the chemicals industry for the production of phosphorus chlorides, oxides, and sulphides. Ferrophosphorus, a by-product of elemental phosphorus production, is used in certain steels and in the manufacture of brake shoes for automobiles. Calcium silicate slag, a second by-product, is used as a base material in road construction.

Phosphate Chemicals

There are three principal groups of phosphate chemicals: calcium phosphate, ammonium phosphate, and sodium phosphate. These are formed by the reaction of high-purity furnace acid with calcium, ammonium and sodium compounds. Calcium phosphate is used as a mineral supplement in animal feedstocks and in the manufacture of paper; ammonium

phosphate is used as a fertilizer and as a fire retardant; and sodium phosphate is used in detergents and soaps, in pharmaceutical chemicals, and in water treatment.

MINING AND PROCESSING

There is no mining of phosphate in Canada at present and processing is limited to the acidulation and furnace treatment of imported phosphate rock. Possibly the most favourable deposit for development in Canada is the Cargill phosphate deposit near Kapuskasing in northeastern Ontario. The development of this deposit would probably be by open-pit methods. Processing would entail crushing, sizing, flotation and, possibly, magnetic separation.

Canada's chief source of phosphate rock is the United States, the bulk of our requirements being supplied by Florida with lesser amounts being supplied by Montana. Strip mining accounts for over 90% of the United States production because of the tabular and bedded nature of deposits. Igneous, carbonatite-type deposits, being more limited in size and of greater depth, are normally operated by open-pit or underground mining methods.

The bulk of phosphate rock mined in the United States is beneficiated by washing, sizing, and flotation. Magnetic separation, as warranted, may be employed to remove iron minerals, and highly carboniferous ores may require calcining to reduce organic material which causes excess foaming during acidulation and darkens the acid colour. Calcining usually is carried out in a fluidized-bed calciner at 800°C or higher. An initial screening step may be employed to reduce coarse, plus 1.2 mm limestone and dolomite which are acid consumers. Washing by cyclones or by wet screening may be required to remove minus 100 μm, high-clay slimes which consume reagents during flotation, and acid during the acidulation process. The minus 1.2 mm plus 100 μm fraction may then be further reduced and sized prior to flotation.

Anionic flotation is used in the rougher circuit to float fine phosphate (minus 420 μm), and cationic flotation is used in the cleaner circuit to remove quartz from the phosphate. The anionic collectors used for phosphate flotation are fatty acids which include crude tall oil, blends of fatty acids, and soap skimmings. The cationic collectors used for silica flotation include tallow amines and condensed amines (13).

Typical flow diagrams for Florida phosphate rock, incorporating washing and flotation, and for western United States rock, incorporating crushing/grinding, washing and calcining, are shown in Figures 2 and 3, respectively.

PRODUCTION, TRADE AND CONSUMPTION (4)

Canada's requirement of phosphate rock for phosphate fertilizer manufacture is met by imports, there being no domestic production of phosphate rock at present. Total imports of ground and unground phosphate rock in 1990 were 1.258 Mt valued at $53.9 M. About 35% of this amount was from the United States, from phosphate mines in Florida and Montana. Togo, a large supplier, accounted for 781,738 t, 65% of our total imports, in 1990. This rock was used in the manufacture of phosphate fertilizers at four plants, one in eastern Canada, at Belledune, New Brunswick, the remaining three in the west, two in Alberta, at Fort Saskatchewan and Redwater, the third at Trail British Columbia. Relatively minor amounts of imported phosphate are used in the manufacture of elemental phosphorus at Varennes, Quebec.

Canada exports packaged fertilizer products to a number of countries including the United States and Jamaica. Exports in 1989 were 85,683 t value at $20 M. Canada also imports various grades of phosphate fertilizers and chemicals. Imports in 1989, chiefly from the United States, were 541,179 t valued at $144 M.

Imports of phosphate rock for 1989 and 1990, and consumption for 1988 and 1989, are tabulated in Table 3. Data relative to Canada's four phosphate fertilizer production facilities are shown in Table 4.

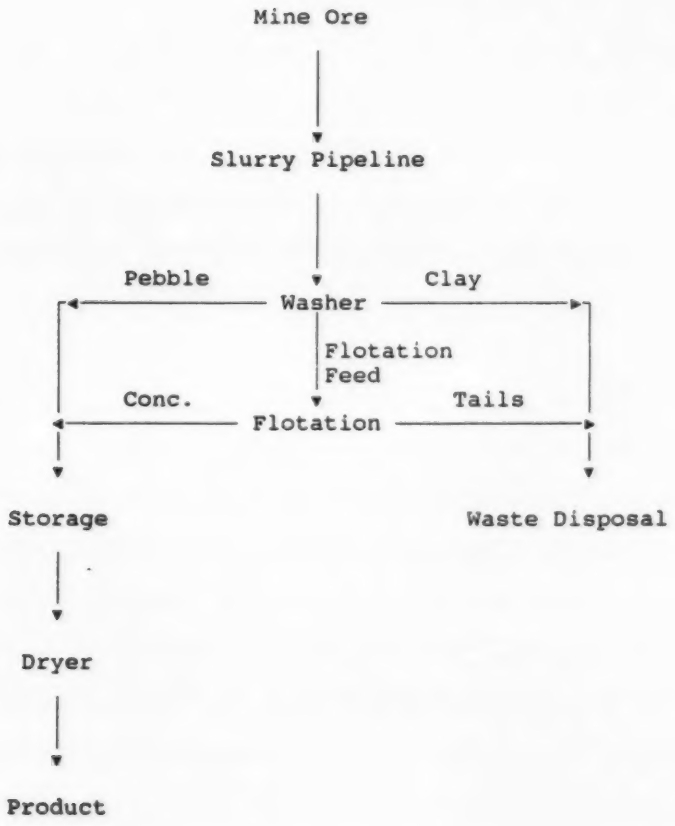

Figure 2 - Schematic Flow Diagram for Florida Phosphate (13)

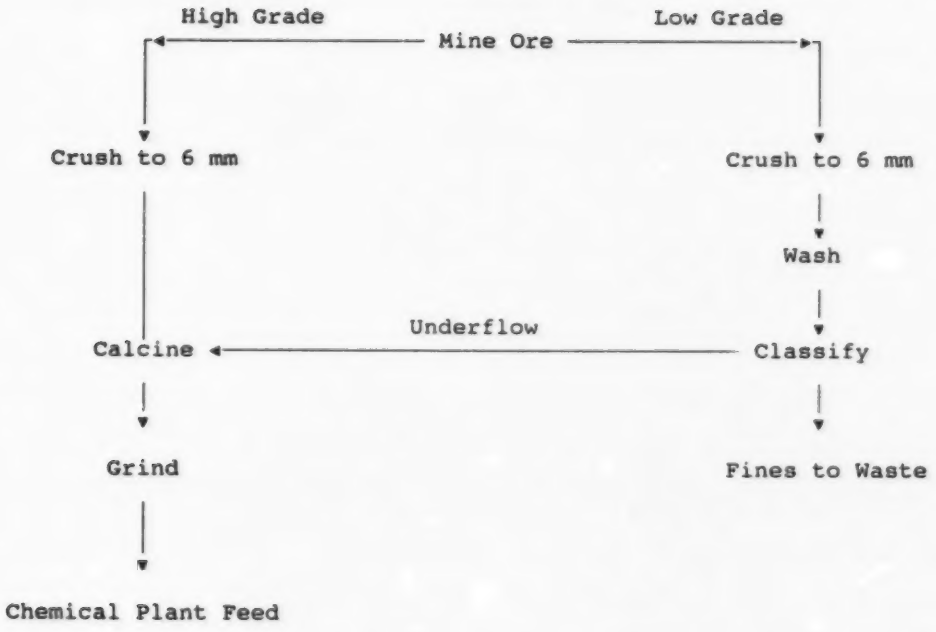

Figure 3 - Schematic Flow Diagram for Western Phosphate (13)

Table 3 - Canada, Phosphate Rock Imports, 1989 and 1990, and Consumption, 1988-89

Item No.		1989		1990	
		(tonnes)	($000)	(tonnes)	($000)
Imports					
2510.10					
Natural calcium phosphates, aluminum calcium phosphates, etc., unground	Togo	901 122	41 410	781 738	35 319
	United States	669 374	21 924	305 041	11 005
	Senegal	25 250	633	47 159	1 076
	Total	**1 595 747**	**63 968**	**1 133 939**	**47 400**
2510.20					
Natural calcium phosphates, aluminum calcium phosphates, etc., ground	United States	251 034	13 224	124 174	6 497
	Taiwan	112	6	167	9
	Hong Kong	24	...	11	...
	Total	**251 170**	**13 231**	**124 352**	**6 506**
	Total Imports	**1 846 917**	**77 199**	**1 258 291**	**53 906**
Consumption		1988		1989[P]	
		(tonnes)			
	Eastern Canada	774 309		629 721	
	Western Canada	1 253 541		1 255 021	
	Total	**2 027 850**		**1 884 742**	

Sources: Statistics Canada: Energy, Mines and Resources Canada.
[P] Preliminary; ... Amount too small to be expressed.
Note: Numbers may not add to totals due to rounding.

Table 4 - Canada, Phosphate Fertilizer Plants, 1989

Company	Plant Location	Annual Capacity	Principal End Products	Source of Phosphate Rock	Basis for H_2SO_4 Supply for Fertilizer Plants
Eastern Canada		(tonnes P_2O_5 equivalent)			
Brunswick Mining and Smelting Corporation Limited, Smelting and Fertilizer Division	Belledune, New Brunswick	150 000	am ph	Florida	SO_2 smelter gas
Western Canada					
Cominco Ltd.	Trail, British Columbia	77 300	am ph	Montana	SO_2 smelter gas
Esso Chemical Canada	Redwater, Alberta	370 000	am ph	Togo	Sulphur
Sherritt Gordon Limited	Fort Saskatchewan, Alberta	50 000	am ph	Florida	Sulphur

Source: 1989 Annual Mineral Review, Mineral Policy, Energy, Mines and Resources Canada
P_2O_5 equivalent - Phosphorus pentoxide equivalent; am ph Ammonium phosphates.

CURRENT INTEREST AND DEVELOPMENTS (4)

Current interest in the possible development of Canadian phosphate resources is largely confined to the Cargill deposit, 32 km southwest of Kapuskasing, and the Martison Lake deposit, 80 km northeast of Hearst in northeastern Ontario.

The deposit of greatest economic significance is the Kapuskasing (Cargill) phosphate deposit, where early studies indicated the presence of about 62 Mt of ore grading 19.6% P_2O_5. It has been determined that the deposit contains higher-grade sections totalling 22 Mt grading 27.5% P_2O_5. The best part of the deposit contains 6 Mt grading 33% P_2O_5. This material may be upgraded further by a simple washing procedure to remove associated clay. A second important carbonatite deposit was discovered in 1982 near Martison Lake north of Hearst, Ontario. Higher-grade zones in the deposit contained 57 Mt grading 23% P_2O_5.

In July, 1984, Sherritt Gordon Limited, Campbell Resources Inc. and New Venture Equities Ltd. combined to form a joint venture on two phosphate properties at Cargill and Martison Lake. In 1987, Jacobs Engineering Group Inc. and Blue, Johnson and Associates completed a feasibility study for the Ontario Ministry of Northern Development and Mines. The study concluded that these deposits could become the base for a viable mining operation of approximately 500 000 t/y in the 1990s when supply and demand for phosphate rock are in balance and should prices improve substantially.

In May, 1989, Newphos Limited, a subsidiary of Central Capital Corporation, acquired the right held by Campbell Resources Inc. for both deposits. Newphos Limited agreed to undertake a production feasibility study within 24 months. Meanwhile, in the fall of 1989, a pilot de-sliming mill installed at the Cargill deposit processed 4000 t of high-grade product grading in excess of 36% P_2O_5. The rock was trucked to Hearst and sent by rail for testing to the Sherrit Gordon fertilizer plant at Fort Saskatchewan, Alberta.

Tenneco Canada Inc., a subsidiary of Tenneco, Inc., controls the Canadian elemental phosphorus producer, Albright & Wilson Americas Inc. The company, up until August, 1989, operated two thermal reduction plants in Canada where elemental phosphorus was produced by the smelting of a mixture of phosphate rock, coke and silica.

Albright & Wilson Americas Inc. closed its Newfoundland, Long Harbour plant in 1989. The company will continue to operate a small electric furnace for a few years to process "mud" stockpiled on site and to produce about 10 t/wk of phosphorus. The Government of Newfoundland is currently conducting an environmental impact study on the plant's closure and its clean-up. The Long Harbour plant had an original capacity of 60 000 t/y.

The other Albright & Wilson Americas Inc. facility, with a 22 500 t/y elemental phosphorus capacity, is located at Varennes, Quebec. The plant operated near optimum capacity levels in 1989 and shipped most of its product to the parent company's operations at Buckingham, Quebec, and at Port Maitland, Ontario. Elemental phosphorus at those two plants is used to produce technical and food-grade phosphoric acid (95% H_3PO_4), and amorphous red phosphorus.

In the 1989 review of phosphate, Barry (4) commented as follows:

> "The outlook for 1990 is for a continuation of demand at the current levels, with ample supply and prices that will continue the moderate improvement that began in 1989. Significant price improvements are not to be expected until supply and demand approach a balance, which may not be before the 1992-93 period. A leading consulting firm forecasts a rapid increase in the unit price of phosphate rock (basis 70% BPL) to approximately US$45/t in 1995 from the current US$27/t f.o.b. vessel Tampa. Although the timing may be a little too optimistic, as prices approach that level, a deposit such as Cargill could become a viable development."

BY-PRODUCTS

Phosphate rock contains several minerals that are potentially recoverable as by-products of phosphate fertilizer manufacture. These include uranium (U_3O_8), recoverable from phosphoric acid; vanadium (V_2O_5), recoverable from ferrophosphorus; and fluorine (F). Two associated by-products are gypsum and calcium silicate slag. The former is a waste product of the production of phosphoric acid, and the latter a co-product of the electric furnace treatment of elemental phosphorus.

Uranium

Most phosphate rock deposits contains small quantities of uranium. This uranium is concentrated during phosphate recovery processes and generally ranges from 50 to 200 ppm U_3O_8 in the phosphate concentrate (2). The uranium is dissolved with the phosphate rock during the acidulation process for the manufacture of phosphoric acid. It may be extracted from the acid by a complex solvent extraction process and concentrated as a hydrated peroxide salt commonly referred to as "yellow cake". Although uranium salt recovery has been practised at one or two phosphate fertilizer plants in Alberta, there is no recovery of phosphate rock uranium in Canada at present.

Vanadium

Vanadium is present in the ferrophosphorus produced during the electric furnace manufacture of elemental phosphorus. Vanadium pentoxide is potentially recoverable from ferrophosphorus, however, there is no recovery in Canada at present.

Fluorine

The fluorine content of phosphate rock averages 3 to 4%. Some of the fluorine escapes as gas during the acidulation process; the remainder is retained in the phosphoric acid as well as in the gypsum by-product. Fluorine in the gaseous phase represents about 35% of that inherent in the phosphate rock. This is recovered as fluosilicic acid by water scrubbing and used in water fluoridation and in the production of cryolite for use by the aluminum metal industry.

Phosphogypsum

Phosphogypsum is formed by the reaction of sulphuric acid on ground phosphate rock. This reaction may be represented as follows:

$$3Ca_3(PO)_4)_2.CaF_2 + 10H_2SO_4 + 2H_2O \rightarrow 6H_3PO_4 + 2HF + 10CaSO_4.2H_2O$$

The gypsum is separated from the phosphoric acid by filters, slurried with water, and pumped to waste disposal areas. The material is finely divided, acidic and, on a dry basis, usually contains more than 90% gypsum. Common impurities include unreacted or partially reacted phosphate rock, organic material, calcium fluoride and quartz sand. This gypsum normally is considered to be a waste product, although there has been much research on the potential use of this material in gypsum products manufacture. There is some utilization of phosphogypsum for gypsum products in Japan and Germany but none in either Canada or the United States. Minor quantities are used as a direct application land fertilizer and soil conditioner in some countries. Contained uranium (25 to 50 pCi/g) discourages the wider use of this material.

Calcium Phosphate Slag

Calcium phosphate slag occasionally may be used in road and embankment construction but other uses are few in number.

CANMET STUDIES

Phosphate investigations by CANMET and its predecessor, Mines Branch, were limited in number largely because of the ready availability of low-cost phosphate rock from the United States and a general non-interest in the development of higher cost Canadian phosphate resources.

Thirteen CANMET phosphate investigations are summarized in Appendix A. Seven of these were on samples from Quebec, five on samples from Ontario, and one on a sample from British Columbia. The Quebec sample studies, carried out in the 1940s and 1950s, included three apatite samples from the area north of Buckingham and four samples of ilmenite-magnetite-apatite from various locations in the eastern portion of the province. The Ontario sample studies, also carried out in the 1940s and 1950s, included three apatite samples from north of Kingston and two magnetite-ilmenite-apatite samples from the Nemegos area. A more recent study of a British Columbia apatite sample, carried out in 1974, was made on a sample of phosphate rock from the Fernie area in the southeastern part of the province.

A study by the Quebec Department of Mines is summarized in Appendix B. This study, undertaken in 1947, was on phosphate samples from the High Rock Phosphate Mine, located about 40 km north of Buckingham.

Quebec

Apatite Samples

The apatite content of the samples studied varied from a low of 20 to a high of 85% ($Ca_3(PO_4)_2$). Impurities included pyroxenite and silicate gangue minerals with mica, calcite, pyrite and pyrrhotite. Various gravity-based separation methods were investigated, including tabling, jigging, and Humphreys spiral concentration, with only limited success because of the close proximity of the specific gravities of the apatite and major impurities (pyroxenite and silicates). Flotation studies were more successful. Flotation of minus 300 μm, deslimed products resulted in grades approaching 70% apatite with recoveries of 75% and better.

Ilmenite-Magnetite-Apatite Samples

The apatite contents of the ilmenite-magnetite-apatite complex samples were much lower than those of the apatite samples and varied from a low of 4.5 to a high of 22.8% ($Ca_3(PO_4)_2$). Impurities generally consisted of ilmenite, magnetite, titanite, pyroxenite and feldspar. Processing included crushing, grinding, sizing, magnetic separation and flotation. High-intensity, wet magnetic separation generally resulted in a concentrate acceptable for use in fertilizer production (37.4% P_2O_5) with recoveries approaching 80%. Flotation was also successful, yielding products grading 30% P_2O_5 with recoveries of 80% or more. Thus recovery of a fertilizer-grade phosphate by-product from ilmenite-magnetite operations would be technically feasible.

Apatite Fusion

The fusion of apatite with other materials available in the Buckingham area of southwestern Quebec, to make a soluble phosphate fertilizer, was investigated intermittently by C.G. Bruce of Mines Branch, Ottawa, between 1949 and 1955. This study was in response to interest by industry, following World War II, in reviving the phosphate fertilizer industry that flourished

in that region during the closing years of the 19th century. Bruce's work was reviewed by Reeves in 1960 (14).

Bruce's studies were based on a process developed in the early 1940s for the electric-furnace fusion of phosphate rock with magnesium silicates, e.g., olivine and serpentine, followed by water-quenching of the resulting slag. Initial studies were conducted using mixtures of ground, minus 200 μm apatite and pyroxenite. These were followed by mixtures containing, as well, ground brucite tailings. The prepared samples were melted in a small electric muffle furnace at 1370 to 1500°C over a 10 to 35 min. period and the molten product rapidly quenched in water. A total of over 30 different mixtures were evaluated. The best results indicated 86.3% available P_2O_5 from a sample analyzing 14% P_2O_5. This sample was composed of an apatite:pyroxenite:brucite tailings of composition 2:1:1. Although of academic interest, fertilizers produced by apatite fusion cannot today compete with fertilizers produced by the acidulation of sedimentary phosphates.

Ontario

Kingston Area Samples

The apatite content of the Kingston area samples varied from a low of 10% to about 25% P_2O_5. Impurities included calcite with minor mica, hornblende, pyroxene and magnetite. Processing included magnetic separation, gravity separation, and flotation. A low-grade sample did not appear to respond markedly to the beneficiation processes employed; however, a higher grade sample (25% P_2O_5) was successfully upgraded to 35% P_2O_5 with a recovery of 70% or more. Magnetic separation and air-tabling on plus 200 μm material (Ont. 3) resulted in a concentrate grading 38.3% P_2O_5 with a recovery of 52.3%. A procedure involving calcining followed by slaking, screening and magnetic separation yielded a plus 200 μm concentrate grading 37.7% P_2O_5 with a recovery of 83.0% for the same sample.

Nemegos Samples

Diamond drill core samples from the Nemegos area contained about 20% apatite with 70% or more of magnetite-ilmenite and other ferro-magnesian minerals. Humphreys spiral treatment of sized fractions resulted in a product grading 75% apatite (34% P_2O_5) with a recovery of 15 to 20% of the feed weight. The second study, of a minus 600 μm apatite concentrate containing feldspar and ferro-magnesium minerals, included air tabling and magnetic separation processing. Although low-intensity magnetic separation trials were not successful, the combination of high-intensity magnetic separation with air table treatment resulted in an overall recovery of 65% of the original sample with an iron content of only 0.3% Fe.

British Columbia

The two Fernie area samples analyzed only 10 to 11% P_2O_5 with major calcite and minor quartz, feldspar and mica. Processing included stage-crushing, sizing, attrition scrubbing and ultrasonic cleaning. A high-grade product grading 30 to 31% P_2O_5 was achieved; however recoveries were low at about 30%.

OTHER STUDIES

Quebec

The Quebec samples, from the High Rock Phosphate Mine, were primarily samples of waste dump material. Grades averaged 30.8 to 55.4% apatite. These samples were successfully upgraded by flotation to from 74 to 90% apatite (33.8 to 40.9% P_2O_5) with recoveries of from 75 to 92%.

CONCLUDING COMMENT

This report, Phosphate, is the twelfth in the CANMET Summary Report Series on industrial minerals in Canada. Other reports, in order of publication, are as follows: Barite; Celestite; Fluorite; Silica; Mica and Vermiculite; Graphite; Gypsum and Anhydrite; Talc and Pyrophyllite; Magnesite, Brucite and Dolomite; Kyanite, Sillimanite and Andalusite; and Nepheline Syenite and Feldspar.

It is hoped that the information presented in these reports will be of use to all having an interest in industrial minerals in Canada.

A wide distribution of the *Summary Report* series is planned as a means of encouraging interest and further development of the "non-metallics" that are becoming of increasing interest for use in many diverse applications such as fillers for paint and rubber and, in the high-technology sector, for products such as high-performance plastics, silicon chips and fibre-optic filaments.

The authors encourage feedback from reports in this series. Comments and suggestions for further R&D will assist CANMET and associated government and industry groups in planning and conducting research on industrial minerals.

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APPENDIX A

CANMET REPORT SUMMARIES

APPENDIX A

CANMET REPORT SUMMARIES

QUEBEC

Identification	:	Que.-1 (Ref. No. 15)
Report - Title	:	CONCENTRATION OF APATITE FROM BUCKINGHAM AREA
- Author	:	Anon.
- No. and Date	:	*Investigation Report* 4158 (1941)
Sample Description	:	Three sample lots, as follows: No. 1 - 280 kg of hand-cobbed, minus 25 mm rejects from an apatite operation in Portland West Twp. (23.6% P_2O_5, 85.2% $Ca_3(PO_4)_2$; sample principally consisted of green apatite and greenish-gray pyroxenite with 10% mica, calcite, and pyrrhotite. No. 2 - 13 kg representative of coarse, hand-cobbed product (27.1% P_2O_5, 59.3% $Ca_3(PO_4)_2$. No. 3 - 25 kg representative of 10 mm shipping product (27.1% P_2O_5, 59.3% $(Ca_3(PO_4)_2$.
Objective	:	To prepare an apatite concentrate from sample No. 1 equivalent to that of sample No. 3.
Processing	:	Various techniques were employed in an attempt to upgrade material represented by sample No. 1, including crushing and selective screening, jigging, tabling and magnetic separation.
Results	:	Gravity methods (jigging and tabling) and magnetic separation were not effective in separating the apatite from the pyroxenite. Selective screening results indicated some tendency for the apatite to concentrate in the finer sizes; screening at 5 mm, for example, resulted in a minus 5 mm product analyzing 63% $Ca_3(PO_4)_2$ with a 61% recovery of the $Ca_3(PO_4)_2$. Superior grades and product recovering undoubtedly could be obtained by flotation.

Identification : Que.-2 (Ref. No. 16)

Report - Title : FLOTATION OF APATITE FROM HIGH ROCK MINES, PORTLAND WEST TOWNSHIP, PAPINEAU COUNTY

- Author : H. Smedley
- No. and Date : *Investigation Report* 4211 (1943)

Sample Description : "High Rock - Sample D, Large Dump", a 135 kg sample of crushed, minus 1.2 mm ore from the Quebec Bureau of Mines. The ore contained 15.66% apatite in a silicate gangue with minor amounts of pyrite and calcite.

Objective : To concentrate the apatite.

Processing : Several preliminary flotation tests were made to determine the type and quantity of reagents required. The sulphides were first removed using standard procedures. Pine oil and cresylic acid were separately used in two tests as frothers. Following the removal of pyrite, oleic acid and kerosene were used to float the apatite.

Results : Apatite recoveries for two typical flotation tests are summarized as follows:

Test No. 1	Wt %	Apatite %	Distribution %
1st conc.	16.8	70.0	78.2
2nd conc.	4.6	39.3	12.0
Test No. 2			
1st conc.	11.5	74.7	58.9
2nd conc.	9.1	50.8	31.7

It was noted that the second concentrate could be further processed to recover up to 50% of the contained apatite.

Identification : Que.-3 (Ref. No. 17)

Report - Title : REPORT ON APATITE ORE FROM PORTLAND TOWNSHIP, LABELLE COUNTY, QUEBEC

- Author : H.L. Beer
- No. and Date : *Investigation Report* 2567 (1949)

Sample Description : Three separate samples were received and processed: No. 1 - 60 kg, 64.6% fluorapatite; No. 2 - 110 kg, 58.3% fluorapatite; and No. 3 - 214 kg, 22.9% fluorapatite. The ore samples mostly consisted of massive green apatite and greenish-gray pyroxene with amber mica, pink calcite, massive pyrrhotite, and pyrite. The apatite was mostly present as free grains up to 2.5 cm in diameter. The sample was from the Buckingham area and was submitted by the Quebec Smelting and Refining Limited, Montreal.

Objective : To recover an apatite concentrate.

Processing :

Sample No. 1
Representative portion of this sample were crushed to minus 850 μm and treated by the Humphreys spiral concentrator.

Sample No. 2
Representative portions of this sample were crushed to various sizes, screened, and the screen fractions analyzed. Representative portions were also treated by Wilfley table concentration.

Sample No. 3
Representative portions of this sample were crushed to minus 850 μm, treated for 10 min with caustic soda, fuel oil, oleic acid, and reagent No. 708 in a conditioning tank, and concentrated (by agglomeration) on a Wilfley table.

Sample No. 4
Representative portions of this sample were reduced to 850 μm and conditioned with the same reagents used with sample No. 3, diluted with water and treated in the Humphreys spiral concentrator.

Que.-3 (Ref. 17) Cont'd

Results : Sample No. 1

The feed material, which analyzed from 63.2 to 65.9% fluorapatite, was upgraded only marginally by Humphreys spiral treatment, from 68.1 to 70.6% fluorapatite.

Sample No. 2

Crushing and sizing test results showed some concentration of fluorapatite as follows:

Feed		Product			
Size (mm)	Fluorapatite %	Size (mm)	Wt %	Fluorapatite %	Distribution %
-35	48.8	-25	78.0	54.0	86.3
-25	58.2	-18	77.4	61.7	82.1
-18	55.7	-12	84.3	58.9	89.1
-10	70.8	-10	87.5	72.0	89.1

Sample No. 3

Wilfley tabling produced only a minimal concentration, e.g., from 68.1 to 75.6% fluorapatite, from 71.6 to 78.9, and from 69.4 to 71.4%, in typical tests.

Agglomeration tabling, by contrast, resulted in a much greater concentration, from 19.8% fluorapatite in the feed to 33.2% in the concentrate, and 26.0% in the No. 1 tailing product. The analysis of the head feed, at 19.8% fluorapatite, was quite low compared with that of the head feed for normal tabling. Sizing of the agglomeration table concentrate showed a greater concentration of fluorapatite in the coarser fractions (74.2% in plus 200 μm fraction) than in the finer (18.7% in the minus 75 μm fractions).

Humphreys spiral agglomeration produced only a minor upgrading of the fluorapatite, e.g., from 30.1 to 42.9% fluorapatite (Test 58). The author notes that grades were low in all tests because the bulk of the mica reported in the fluorapatite concentrate.

Identification : Que.-4 (Ref. No. 18)

Report - Title : CONCENTRATION TESTS ON A TITANIFEROUS MAGNETITE-APATITE ORE FROM ST. CHARLES, SAGUENAY RIVER DISTRICT

- Author : H.L. Beer
- No. and Date : *Investigation Report* 2213A (1947)

Sample Description : A composite ore sample analyzing 34.84% iron (Fe), 12.76% TiO_2, 9.65% P_2O_5 (22.8% apatite) and 0.14% V_2O_5; from Quebec Metallurgical Industries Ltd., Montreal.

Objective : To recover a phosphate concentrate.

Processing : A representative sample was ground to 300 μm, treated by wet magnetic separation, and the non-magnetic fraction deslimed prior to flotation tests. A variety of flotation reagents were used including caustic soda, oleic acid, crude oil and Emulsol No. X-1; cleaning agents included caustic soda and sodium silicate; flotation was carried out at pH 10.6. The flotation concentrate was dried and treated by magnetic separation.

Results : Typical test results were as follows:

Wet magnetic separation plus flotation (Test No. 1A)

Product	Wt %	P_2O_5 %	Distribution %
Feed	100.0	13.7	100.0
Conc.	29.8	37.4	81.2
Midds.	8.1	19.5	11.5

Final product analyses (wet magnetic separation, flotation, dry magnetic separation) were as follows:

	P_2O_5 %	Fe %	TiO_2 %	Distribution %
Test 1	41.43	0.28	0.02	75.2
Test 2	41.44	0.38	0.09	76.7

Identification : Que.-5 (Ref. No. 19)

Report - Title : FLOTATION CONCENTRATION OF A MAGNETITE-ILMENITE-APATITE ORE FROM LAKE ALLARD

- Author : H.L. Beer
- No. and Date : *Unnumbered Report* (1953)

Sample Description : Five samples (No. 1, minus 1.2 mm; No. 2, minus 840 μm; No. 3; minus 600 μm; No. 4 minus 420 μm; No. 5, minus 200 μm) of Wilfley table tailings from the previous concentration of magnetite and ilmenite by wet tabling; apatite content varied from 4.5 to 6.0% P_2O_5.

Objective: : To recover an apatite concentrate from Wilfley table tailings.

Processing: : Portions of samples 1 to 4 were further ground to 200 μm, deslimed, and all five samples treated by flotation using sodium hydroxide as a conditioner, Emulsol X1 as a frother, and reagent 708 and fuel oil to float the apatite. The rougher concentrate was cleaned once with sodium hydroxide and sodium silicate. Flotation concentrates from various tests were treated in a Frantz ferrofilter and Carpco magnetic separator to remove residual ilmenite and magnetite.

Results : Results indicated that grinding to at least minus 300 μm is required to liberate the apatite prior to flotation. At minus 200 μm (sample No. 5), the flotation concentrate analyzed 30.4% P_2O_5 with a recovery of 84% of the apatite in the feed, although the iron and titanium contents, at 7.8% Fe and 0.9% TiO_2, were relatively high. Magnetic separation did not appear to significantly reduce the iron and titanium contents. Typical results are summarized as follows:

Sample No.	Flotation Concentrate		
	Weight %	P_2O_5 %	Distribution % P_2O_5
1	18	18.5	73.6
2	16	22.2	71.9
3	17	20.0	75.8
4	23	22.0	82.1
5	12	30.4	83.8

Identification	:	Que.-6 (Ref. No. 20)
Report - Title	:	SEPARATION OF APATITE FROM MAGNETITE AND ILMENITE
- Author	:	W.J.D. Stone
- No. and Date	:	*Industrial Minerals Report* 58-121 (November, 1958)
Sample Description	:	The sample, from the St. Hilaire area, weighed 25 kg and was composed of lumps ranging from 5 to 15 cm in size. The chief mineral constituents were magnetite and ilmenite; the apatite content was estimated at 8% (P_2O_5).
Objective	:	To recover an apatite concentrate containing a minimum of 31% P_2O_5 with a maximum iron content of 1% (Fe_2O_3).
Processing	:	The sample was stage-crushed by jaw and rolls crushers to 600 μm and screened into four size fractions: minus 600 plus 200 μm, minus 200 plus 150 μm, minus 150 plus 75 μm, and minus 75 μm. The first two sizes were treated by air tabling and the resulting products passed over a magnetic pulley to remove magnetite and treated several times in a high-intensity magnetic separator to remove ilmenite. Results indicated non-separation of the apatite from gangue minerals in the minus 600 plus 200 μm fraction; this fraction was reground to minus 200 μm and retreated. The minus 75 μm fraction, being too fine for dry magnetic separation, was not treated.
Results	:	The recovered, minus 200 plus 75 μm product analyzed 39.5% P_2O_5 and 0.33% Fe, well within the identified specifications; product recovery was about 45%. The minus 75 μm fines represented about 30% of the total sample weight and contained an estimated 10% P_2O_5. Treatment of this fraction by high-intensity wet magnetic separation would improve the overall recovery and grade of the final apatite concentrate.

Identification	:	Que.-7 (Ref. No. 21)
Report - Title	:	CONCENTRATION OF A SAMPLE OF APATITE FROM QUEBEC
- Author	:	J.E. Reeves
- No. and Date	:	*Industrial Minerals Report* 59-14 (February 1959)
Sample Description	:	A 135 kg sample from the Mont St. Hilaire area. The apatite content was estimated at 9% P_2O_5 (apatite); associated minerals included magnetite, ilmenite, pyroxene, and feldspar.
Objective	:	To recover a concentrate analyzing at least 31% P_2O_5 with a maximum iron content of 1% (Fe_2O_3).
Processing	:	The sample was stage-reduced by jaw and rolls crushers to 200 μm to free the apatite, and treated by wet table to separate the feldspar. The apatite concentrate from the table was dried and treated by high-intensity magnetic separation to remove iron minerals.
Results	:	The non-magnetic fraction from the magnetic separator analyzed 34.43% P_2O_5 and 0.67% Fe_2O_3; product recovery was 42%.

ONTARIO

Identification	:	Ont.-1 (Ref. No. 22)
Report - Title	:	CONCENTRATION OF APATITE FROM THE BEDFORD AREA
- Author	:	H.L. Beer
- No. and Date	:	*Unnumbered Report* (1945)
Sample Description	:	A 4.5 t shipment of phosphate ore from Ontario Phosphate Industries Ltd. property near Bedford, Ontario. Sample was minus 950 mm in size and analyzed 54.21% B.P.L. [$Ca_3(PO_4)_2$].
Objective	:	To obtain a saleable phosphate concentrate from this ore.
Processing	:	Processing included dry magnetic separation of sized feed as well as flotation of ground, deslimed product (48% minus 75 μm). Flotation reagents included sodium silicate, sodium hydroxide, coal oil and oleic acid.
Results	:	Magnetic separation of ground, plus 200 μm ore resulted in a concentrate analyzing 81% B.P.L. with a recovery of 72% of the contained B.P.L. The minus 200 μm product analyzed 60% B.P.L. Flotation concentrate analyses ranged from 78.3 to 79.4% B.P.L. with recoveries of from 74.5 to 71.0% B.P.L.

Identification : Ont.-2 (Ref. No. 23)

Report - Title : FLOTATION CONCENTRATION OF APATITE ORE FROM KINGSTON AREA

- Author : H.L. Beer
- No. and Date : *Unnumbered Report* (1953)

Sample Description : A 45 kg sample of low-grade ore from Strategic Metals Ltd. containing about 10% apatite in 80% or more of calcite with minor mica, magnetite, pyroxene and sulphides.

Objective : To recover an apatite concentrate.

Processing : A representative portion of the sample was ground to minus 300 μm and treated by magnetic separation. The non-magnetic fraction was treated by cationic flotation, to float mica at pH 8, followed by flotation of apatite at pH 10.5 using a variety of reagents.

Results : The results of two typical flotation tests are summarized as follows:

Test No. 2B	Wt %	Apatite % (P_2O_5)	Distribution %
Conc.	26.1	15.88	71.0
Midds.	10.1	5.36	9.3
Test No. 5			
1st Conc.	6.1	14.95	15.1
2nd Conc.	9.2	21.82	33.3
Midds.	20.4	10.25	34.7

Identification : Ont.-3 (Ref. No. 24)

Report - Title : CONCENTRATION OF APATITE FROM THE KINGSTON AREA

- Author : W.J.D. Stone
- No. and Date : *Investigation Report* 59-90 (1959)

Sample Description : A 75 kg sample composed chiefly of calcite, apatite, biotite, hornblende and magnetite; apatite content estimated at 15%; sample submitted by Franc R. Joubin and Associates of Toronto.

Objective : To recover an apatite concentrate.

Processing : Two processes were investigated:

(1) crushing to 200 μm, separate air table treatment of the plus 200 μm fractions (77.5% of sample), combination of the high-apatite concentrates, and magnetic separation of the resulting product; treatment of the minus 200 plus 150 μm fraction (10.5% of sample) by flotation using caustic soda, fuel oil, Emulsol X-1 and tall oil.

(2) calcining the "as received" lump material to convert the calcite to quicklime (2 hrs @ 1000°C) followed by slaking and screening to remove the hydrated lime and to recover the non-lime solids, magnetic separation to remove iron minerals.

Results : (1) The combined results for air table and magnetic separation of the plus 200 μm material are summarized as follows:

	Apatite %	P_2O_5 %	Distribution % (apatite)
Head	18.7	-	84.2
Concentrate	96.0	38.3	52.3
Middlings	38.0	-	19.2
Tailings	3.4	-	12.7

Flotation results on the minus 200 plus 100 μm fraction were inconclusive; the best result achieved was a concentrate grading 55% apatite at a recovery of 38%.

Ont.-3 (Ref. No. 24) Cont'd

Results : (2) The results from the calcining, slaking, screening and magnetic separation study are summarized as follows:

Fraction	Wt %	P_2O_5 %	Distribution % (P_2O_5)
+200 μm non-magnetic	13.7	37.7	83.0
+200 μm magnetic	35.4	2.0	11.6
- 200 μm mesh	50.9	0.7	5.4

Identification	:	Ont.-4 (Ref. No. 25)
Report - Title	:	LABORATORY TEST ON APATITE FROM NEMEGOS
- Author	:	C.G. Bruce
- No. and Date	:	*Industrial Minerals Report* 306 (1955)
Sample Description	:	A 100 kg sample of ground minus 600 μm apatite concentrate; principal impurities were feldspar, ferro-magnesian silicates, and pyrrhotite; finely disseminated magnetic iron was observed with smaller particles of apatite.
Objective	:	To prepare a product containing less than 0.5% iron (Fe).
Processing	:	Removal of ferro-magnesian impurities was investigated by treating various size fractions by air table, and by low- and high-intensity magnetic separation.
Results	:	Air tabling and low-intensity magnetic separation were essentially ineffective in reducing the iron content below the specified 0.5% (Fe). A composite of products meeting this specification was prepared — it represented 65% of the weight of the original sample and analyzed 0.30% iron (Fe).

Identification	:	Ont.-5 (Ref. No. 26)
Report - Title	:	CONCENTRATION OF MAGNETIC-APATITE ORE FROM NEMEGOS
- Author	:	C.G. Bruce
- No. and Date	:	*Industrial Minerals Report* 335 (1955)
Sample Description	:	A 200 kg sample of crushed diamond drill core containing approximately 20% apatite, 70% magnetite-ilmenite, and including pyrrhotite, biotite, other ferro-magnesian minerals, garnet and quartz, (from Multi-Minerals Limited).
Objective	:	To devise a suitable flow sheet (process) for the concentration of apatite.
Processing	:	A 50 kg sample was reduced by impact crusher and screened at 420 μm; the plus 420 μm fraction was further reduced by hammer mill and all three fractions (minus 420 μm from impact crusher, and plus 420 and minus 420 μm from the hammer mill) were treated in a Humphreys spiral classifier.
Results	:	Recovery of apatite concentrate grading 75% varied from 16 to 22% of feed weight.

The author concluded that the Humphreys spiral could be usefully employed to prepare:

(a) uncontaminated metallics in sizes ranging downward from about 2 mm.
(b) a relatively high grade apatite concentrate for further retreatment by magnetic separation.
(c) a finer apatite product suitable for concentration by flotation.

BRITISH COLUMBIA

Identification	:	B.C.-1 (Ref. No. 27)
Report - Title	:	BENEFICIATION OF PHOSPHATE ROCK FROM FERNIE
- Authors	:	F.H. Hartman and R.A. Wyman
- No. and Date	:	*Investigation Report* 74-37 (July 1974)
Sample Description	:	Two samples from Lodgepole Creek near Fernie, one a bulk trench sample, the other drill core from three holes. The trench sample was dark brown, earthy, contained lumps up to 5 mm in size, and analyzed 10 to 11% P_2O_5 (apatite) with 20% calcite, quartz, feldspar, and some mica and mafic minerals. The core sample weighed 50 kg and was of low-grade.
Objective	:	To investigate the technical feasibility of recovering the contained phosphate.
Processing	:	Processing was restricted to the bulk sample which was believed to be representative of the material potentially recoverable from this deposit. A representative sample was dried and stage-reduced to 600 μm by hammer mill. Variously sized fractions were then treated mechanically, by attrition scrubbing and ultrasonic cleaning, and by flotation, with and without ultrasonic treatment.
Results	:	The highest grade product was obtained by attrition scrubbing and ultrasonic treatment, grades of 30 to 31% P_2O_5 being achieved with recoveries of 30 to 31%. Flotation concentrates averaged 28 to 29% P_2O_5 with recoveries approaching 50%. Flotation test results using hot conditioning with soda ash and oleic acid showed the importance of grinding the feed to free the contained phosphate minerals and clean surfaces prior to treatment by flotation.

APPENDIX B

OTHER REPORT SUMMARY

QUEBEC

Identification	:	Que.-8 (Ref. No. 28)
Report - Title	:	HIGH ROCK PHOSPHATE MINE
- Authors	:	P.E. Bourret and B.J. Walsh*
- No. and Date	:	*Unnumbered Report* (1947)
Sample Description	:	Four sample lots were investigated as follows: Lot 1 - 60 kg of dump material with high-grade removed (51.2% apatite) Lot 2 - 45 kg of freshly mined waste (55.4% apatite) Lot 3 - 45 kg of dump material (30.8% apatite) Lot 4 - 45 kg of high-sulphide dump material (29.8% apatite).
Objective	:	To investigate the recovery of a phosphate concentrate by flotation.
Processing	:	All samples were ground to minus 300 μm prior to flotation. Lot 1 - a representative sample was floated using caustic soda, oleic acid and coal oil; another sample (1-A) was deslimed and floated using the same reagents. Lot 2 - a representative sample was floated using the same reagents; a second sample (2-A) was deslimed and floated. Lot 3 - a representative sample was floated to remove sulphides using reagent Z-8, cresylic acid, and caustic soda; apatite was then floated using oleic acid and coal oil. Lot 4 - a representative sample was first floated to remove sulphides followed by flotation to recover apatite as in Lot 3, above.

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* Laboratory flotation studies were carried out by B.J. Walsh.

Que.-8 (Ref. No. 28) Cont'd

Results : Typical flotation test results were as follows:

Test	Wt %	Apatite Concentrate Apatite %	Distribution % (Apatite)
1	63.4	75.6	92.8
1-A	58.1	90.2	92.1
2	67.7	77.8	94.7
2-A	63.5	83.7	94.2
3	34.5	75.1	85.2
4	30.0	74.3	75.5